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Pronghorn Antelope by Dave Menke/
U.S. Fish and Wildlife Service

Drill pads in the Upper Green River
Basin, Wyoming by Peter Aengst

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Fragmenting Our Lands:

The Ecological Footprint from Oil and Gas Development

Ecological Analysis

SCIENCE FROM

THE WILDERNESS SOCIETY

Fragmenting Our Lands:

The Ecological Footprint from Oil and Gas Development

A SPATIAL ANALYSIS OF A WYOMING GAS FIELD

By

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The Wilderness Society

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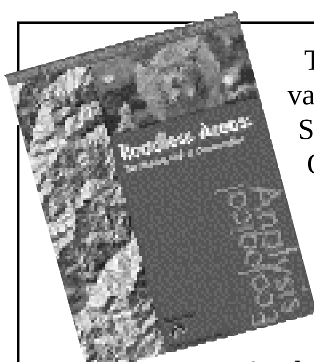
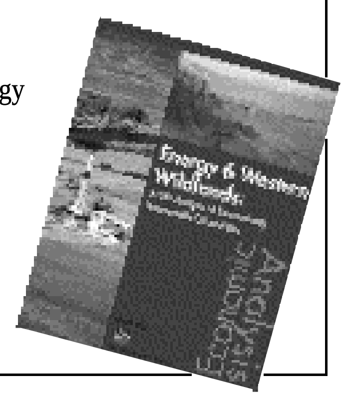


This science report is one of a series that stems from conservation research studies conducted by The Wilderness Society's Ecology and Economics Research Department. Other recent reports in the series include "Roadless Areas: The Missing Link in Conservation (An Analysis of Biodiversity and Landscape Connectivity in the Northern Rockies)" and "Energy and Western Wildlands: A GIS Analysis of Economically Recoverable Oil and Gas." These reports are available on The Wilderness Society's website (www.wilderness.org) or from The Wilderness Society, Communications Department, 1615 M Street, NW, Washington, DC 20036 (202-833-2300 or 1-800-THE-WILD).



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Preface

The magnificent public lands of the western United States sustain healthy ecosystems that provide clean drinking water, recreation, and solitude for millions of Americans, as well as critical habitat for numerous plants and animals. Most Americans recognize that these and other ecological benefits are vital to our quality of life, but often these values are not taken into consideration when logging, mining, and oil and gas exploration decisions are being made.

Through a pilot study of the existing Big Piney-LaBarge oil and gas field in the Upper Green River Basin of Wyoming, "Fragmenting Our Lands: The Ecological Footprint from Oil and Gas Development (A Spatial Analysis of a Wyoming Gas Field)" focuses on the habitat fragmentation that can result from the resource extraction activity. Using The Wilderness Society's state-of-the-art landscape analysis techniques, the report examines the effects of drilling pads, roads, pipelines, water disposal areas, and other infrastructure components and demonstrates the far-reaching impact they have on wildlife species and the surrounding land.

GIS Technician Chris Weller and Landscape Scientist Janice Thomson from the TWS Center for Landscape Analysis in Seattle and Resource Economist Pete Morton and Forest Ecologist Greg Aplet from our Four Corners Regional office in Denver provided analysis and interpretation of the data. Their specific findings offer an important illustration of the ecological consequences of resource extraction, while their particular methods demonstrate the significant benefits of incorporating landscape analyses in future public land resource assessments and planning documents.

William H. Meadows
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Report Highlights

Fragmentation of habitat is widely acknowledged as detrimental to wildlife and plant species. Landscape analysis is a proven method to identify fragmentation and other agents of change in a given area. Yet landscape analysis is seldom completed prior to initiation of oil and gas projects, despite considerable evidence that oil and gas extraction and transmittal are likely to cause wide-ranging disturbances in the landscape.

We conducted a pilot analysis of the landscape of the existing Big Piney-LaBarge oil and gas field in the Upper Green River Basin of Wyoming, a region where more than 3,000 oil and gas wells have been drilled. We measured the degree of habitat fragmentation of the field using three metrics: linear feature density (primarily roads and pipelines), habitat in the infrastructure effect zone, and the amount of habitat in core areas (interior habitat that is remote from infrastructure).

Our results indicate an overall density of 8.43 miles of roads and pipelines per square mile. This is at least three times greater than road densities on national forests in Wyoming, South Dakota, and Colorado and is “extremely high” based on ratings in the Interior Columbia Basin Ecosystem Management Project.

The overall area of oil and gas infrastructure (roads, pipelines, pads, waste pits, etc.) at Big Piney-LaBarge covers 7 square miles of habitat, or 4% of the study area. But the effect of that infrastructure is much greater. The entire 166-square-mile landscape of the field is within one-half mile of a road, pipeline corridor, well head, retention pond, building, parking lot, or other component of the infrastructure. One hundred and sixty square miles—97% of the landscape—fall within one-quarter mile of the infrastructure. With respect to core area, only 27% of the study area is more than 500 feet from infrastructure, and only 3% is more than one-quarter mile away.

Our results, combined with a review of the scientific literature, suggest that there is no place in the Big Piney-LaBarge field where the greater sage-grouse—a potential candidate for the endangered and threatened species list—would not suffer from the effects of oil and gas extraction. And the vast majority of the study area has road densities greater than two miles per square mile, a level estimated to have adverse impacts on elk populations.

Because our results clearly show that oil and gas drilling and extraction cause significant fragmentation of habitat, we recommend that similar spatial analyses be incorporated into the evaluation and monitoring of the ecological impacts of proposed oil and gas projects.

We also recommend the following standards for incorporation into assessments of all future oil and gas production sites on public lands.

- Generate infrastructure scenarios prior to field development.
- Assemble regional habitat-use data.
- Generate landscape metrics for all infrastructure.
- Integrate results into management plans.

1. Introduction

The current administration's National Energy Plan calls for expansion of the amount of public land that is open for oil and gas drilling and includes steps to increase access to federal land. Up to this point, little of the debate over this policy has centered on ecological impacts—the "ecological footprint"—associated with the extraction of oil and gas.

Loss and fragmentation of habitat are among the significant ecological impacts from access roads, drill pads, pipelines, waste pits, and other components of the oil and gas project infrastructure. These impacts extend beyond the physical structures. Studies indicate that the actual ecological footprint of oil and gas extraction stretches across rangelands and forested lands for a considerable distance.[1]

Fragmentation of habitat can be defined as the decrease in the size of habitat patches and interior habitat and the increase in distance between patches (Noss and Csuti 1994). Fragmentation caused by roads, clearcuts, and conversion of wildlands to residential and commercial uses is a growing concern among ecologists, wildlife biologists, and land-use planners (Harris 1984, Wilcove 1987, Knight et al. 2000). The nation's sprawling road network that gives access to communities and resources also fragments wildlife habitat, promotes the spread of invasive non-native species and diseases, and is a major source of sediment in streams. Decisions to build access roads for oil and gas projects, therefore, hold the potential of detrimental and long-lasting ecological impacts on the landscape.

There has been much discussion about the exact size and extent of the ecological footprint, but there has been little, if any, quantitative analysis. Spatial analysis can help fill this information gap. Because fragmentation of habitat occurs across a wide area, the cumulative impacts cannot be adequately addressed at the site level. Rather, analyzing the overall ecological footprint requires spatial analysis of the landscape.

The Bureau of Land Management (BLM) and U.S. Forest Service are the two land management agencies responsible for much of the public land targeted in the administration's energy policy. The two agencies have rarely, if ever, required or completed landscape-level analysis of habitat fragmentation caused by oil and gas projects as part of the evaluation process required by the National Environmental Policy Act.

To address this shortcoming, we completed a pilot spatial analysis of the fragmented landscape of a gas field in the Upper Green River Basin of Wyoming. The objectives of our study are to: 1) estimate the degree of fragmentation associated with oil and gas drilling, 2) inform the public and decision-makers about the impacts to the landscape from oil and gas drilling, and 3) over the long term, improve the quality of BLM and Forest Service environmental analyses of proposed oil and gas projects as part of the National Environmental Policy Act process.

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[1] The ecological footprint also penetrates to shallow aquifers and aquifers thousands of feet below the earth's surface.

2. Study Area

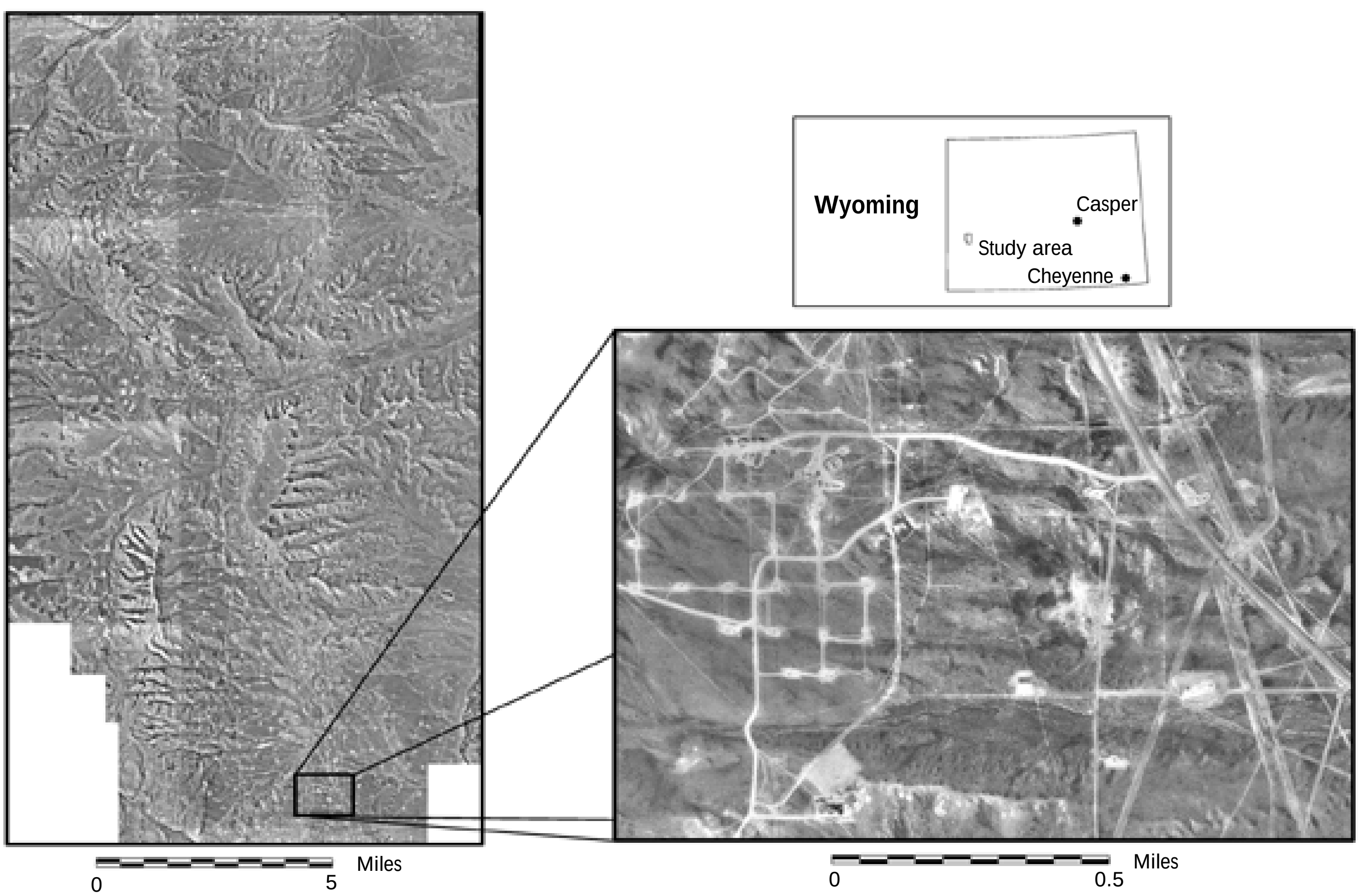
Our analysis focused on the Upper Green River Basin of southwestern Wyoming. This region contains high desert sagebrush framed by the Wind River and Wyoming mountain ranges. The basin, managed primarily by BLM, is a world-class wildlife area. It provides important habitat for 100,000 pronghorn antelope, mule deer, elk, and moose that inhabit the southern Greater Yellowstone Ecosystem and serves as a corridor for the longest big game migration in the continental United States. The basin also provides one of the last strongholds for greater sage-grouse. Wyoming populations of this species declined during the past 20 years, mostly because of loss, degradation, and fragmentation of habitat in shrub-steppe ecosystems (Holloran and Anderson 1999).

The region's rich and varied wildlife populations are popular with local hunters and recreationists. These animals also attract visitors to the region. Natural resource use has played a major role in the history of the Upper Green River Basin. Both ranching and oil and gas production have figured prominently over the last century. More than 3,000 oil and gas wells have been drilled in the

FIGURE 1.

Big Piney-LaBarge oil and gas field

The left image shows U.S. Geological Survey digital orthopotos of the study area. A portion of that image in more detail (right) illustrates infrastructure features of interest.



Upper Green River Basin, and BLM has authorized some 4,500 permits for additional wells (Bureau of Land Management 1999).

Within the Upper Green River Basin, the study area for our pilot project was the Big Piney-LaBarge oil and gas field located between and immediately west of the towns of Big Piney and La Barge in the midst of rangelands managed by BLM. Oil and gas were initially discovered in the area in 1924. The Big Piney-LaBarge gas field is one of the top ten fields in the country with respect to proven gas reserves (Energy Information Administration 1998). As of 1990, the field had a total of 1,864 drilled wells, of which 1,080 were still active (Bureau of Land Management 1990).

The field has produced oil and gas historically, but the current boom in production is largely natural gas. Seventy-two percent of the known gas reserves are predicted to be “tight sands” gas (also called continuous-type gas) (Energy Information Administration 2001), which is classified by U.S. Geological Survey as an unconventional fuel. Exploitation of tight sands gas requires drilling a significant number of wells because the distribution of this gas type is not well understood (U.S. Geological Survey 1996a).

The study area contains a web of infrastructure related to oil and gas drilling, including roads, pipeline corridors, drill pads, retention ponds, compressor stations, buildings, and parking complexes. The original extent of the study area followed the boundaries of 12 U.S. Geological Survey quarter quads (Figure 1). We excluded areas in the southeastern and southwestern corners because they contained infrastructure from activities other than oil and gas projects. Our study area covers 166 square miles.

We selected Big Piney-LaBarge oil and gas field for several reasons. First, the BLM is in the process of examining access to oil and gas in five basins of the Rocky Mountains, and the Greater Green River (containing the Big Piney-LaBarge field) was the first basin examined (U.S. Department of Energy 2001). The area has been targeted “because it contains the largest amount of estimated technically recoverable natural gas resource in the region” (U.S. Department of Energy 2001). The land-use plan for the Upper Green River Basin is one of the 22 “time-sensitive plans” that the administration has placed on a fast track, and revision of the Pinedale Resource Management Plan—the BLM document that will guide management of more than 930,000 acres in the region—is underway. Impacts on wildlife from oil and gas projects are among the most prominent issues related to that plan.

Second, within the Upper Green River Basin the Big Piney-LaBarge field is a developed oil and gas field for which digital aerial photos (dated after substantial oil and gas extraction) were available to conduct a spatial assessment of the landscape.

Third, the area has outstanding wildlife values. It provides important pronghorn antelope, mule deer, and elk winter range. It also contains habitat for the greater sage-grouse, which is under consideration for listing as a threatened or endangered species.

3. Methods

Data Generation

We obtained digital data of the infrastructure of oil and gas activities, including the location of roads, pipeline corridors, and wells within Big Piney-LaBarge gas field, from BLM's Pinedale (Wyoming) field office. However, a comparison of these data to aerial photographs indicated that substantially more roads and other infrastructure exist across the landscape.

We "captured" infrastructure features using 12 digital orthophoto quarter quads that we obtained from the Wyoming Geographic Information Science Center (www.sdvc.uwyo.edu/doqq). These quarter quads were generated with a pixel size of approximately one square meter from 1994 aerial photography.

The number and distribution of quarter quads we selected were based on the need to assess the wide variety of types and densities of infrastructure features that are associated with field development of gas, while minimizing the cost of manual digitizing. The 12 quarter quads we chose capture the bulk of existing (pre-1994) infrastructure at Big Piney-La Barge. However, development does extend beyond our study area boundaries, particularly to the north. Our study area was selected to demonstrate landscape analysis techniques, but was not intended to provide a comprehensive assessment of the field.

We generated our infrastructure data through on-screen digitizing of the features, using a geographic information system (GIS). A GIS analyst identified the features by visual inspection of the quarter quads on the computer screen and then traced them with the cursor to generate new GIS data files. This work was performed with ESRI's ArcView 3.2 GIS software.

We displayed the quarter quads at a scale of 1:10,000 to generate the data. We determined this scale as an acceptable balance, given our goal to capture a majority of the infrastructure features within the study area, while keeping the time and costs of digitizing within reason. Our data sets do not capture a limited number of small features that are difficult to discriminate, including unused roads that may be revegetating. Therefore, our assessment of the overall ecological footprint is likely conservative.

We stored the data in two separate GIS data files, one for linear features such as roads and pipelines and one for polygon features such as drill pads, pumping stations, utility buildings, and retention ponds. We visually reviewed the data to eliminate areas and features that are unrelated to gas development.

Together, the two files show the immediate physical footprint that gas extraction left on Big Piney-LaBarge oil and gas field. This does not take into account the impacts across the larger landscape.

In the spatial analysis of metrics discussed immediately below, we used ESRI's Arc/Info and RoadNET (Road Network Evaluation Tool). RoadNET, a spatially based computer software application that allows quantitative assessments of the fragmentation of landscapes, is a proprietary GIS-based software program developed by Dawn Hartley of The Wilderness Society. RoadNET incorporates Visual Basic and MapObjects technology and runs on Windows 95/98/2000/NT platforms.

Metrics for Measuring Habitat Fragmentation

Roads, pipeline corridors, and other linear features associated with oil and gas projects fragment the landscape by separating patches or core areas of interior habitat with abrupt edges. This creates edge habitat that may give rise to invasion by edge-loving species to the possible detriment of interior species, and it reduces the total area of habitat available. The degree of fragmentation caused by these linear features, as well as the effects of such fragmentation on the ecological composition, structure, and function of a landscape, are difficult to measure and far from fully understood. However, a variety of landscape metrics have been developed to measure the condition of a landscape and its level of fragmentation. For our study, we selected three relatively simple landscape metrics: the density of roads and linear features, the acreage of habitat in the infrastructure effect zone, and the acreage of habitat in core areas.

A comprehensive analysis of fragmentation would incorporate a measure of landscape metrics generated by natural vegetation patterns and geographic features across a landscape prior to oil or gas field development. The infrastructure would then be superimposed and the metrics regenerated for comparison. Because detailed vegetative cover was not available, our study focuses only on fragmentation caused by infrastructure at Big Piney-LaBarge.

> The ecological effects of infrastructure features extend across the landscape beyond physical structures of the oil or gas field.

Density analysis of linear features. Although not an exact measurement of fragmentation, road density is often used as a surrogate for fragmentation. Road density measures the number of road miles per unit area and is a common metric in quantitative assessments of ecological impacts from a landscape perspective. Road density is also an indication of the level of human activity. Road densities increase as more people move onto a landscape.

Roads are only one of the linear features that fragment habitat in an oil and gas field. In this study, the density analyses include all linear infrastructure features, most notably roads and pipelines. At a scale of 1:10,000, we were not always able to distinguish with a high level of certainty the roads from the pipelines at Big Piney-LaBarge, and there are undoubtedly differences in the impacts of roads and pipelines. Nevertheless, all linear features used in the analysis create significant breaks in the vegetative cover, and thus our linear feature density analysis is more comprehensive than a road density analysis alone.

Linear feature density was calculated both as an average for the entire study area and as a series of one-square-mile and four-square-mile sampling windows across the landscape. Measuring density in sampling windows of different sizes provides an understanding of the variability of density across scales, which is important to gauge the effects on different species (Urban

PHOTO COURTESY LINDA BAKER

Physical infrastructure of gas fields, Riley Ridge Natural Gas Project, Upper Green River Basin, WY. The ecological effects of roads, pipelines, drill pads, and other components of the infrastructure extend far beyond the infrastructure itself.

et al. 1987, Wiens and Milne 1989, Turner et al. 1994). For example, differences in dispersal distances among species cause them to respond to habitat features at different scales.

Analysis of the infrastructure effect zone. The ecological effects of infrastructure features extend across the landscape beyond physical structures of the oil or gas field. Forman (1999) calls the influence on edge environments parallel to roads the "road effect zone." We extended this zone of influence to all forms of infrastructure. To measure this metric, we constructed a spatial effect zone around the entire infrastructure associated with gas drilling at Big Piney-LaBarge oil and gas field. Infrastructure effect zone analysis measures both known effects on plant and animal species and changes in the landscape (Baker and Knight 2000).

The width of the effect zone simulates the area affected by gas field development. The effects vary with distance and affect numerous species and human uses. By altering the width of the effect zone, we can simulate various impacts from dust and noise to the pressures of hunting and poaching.

Roads, in particular, have a wide range of effects on the landscape that occur at varying distances from the road. For example, immediately on or adjacent to roads, the obvious impacts are road kill, soil compaction, and altered surface water runoff patterns, among others. For some impacts, the effect zone might be simply the width of the road or a few feet on either side. Farther from the road, say 50 to 100 feet on either side, the impacts may include barriers to wildlife movement, noise, increased dust, and the spread of invasive non-native species. Farther still might be the increased presence of people. In fact, access for people to previously remote areas is perhaps the most significant impact of roads. Such access results in increased legal hunting and illegal poaching pressures on wildlife. It should

PHOTO COURTESY PETER AENGST

Drill rig in the Upper Green River Basin.
The total regional impact of the infrastructure at any one site is magnified by the 3000+ gas and oil wells that have been drilled in the Upper Green River Basin, WY.

be also noted that roads built to service oil and gas projects are often permanent changes to the landscape and therefore represent permanent loss of habitat (Noon 2002).

Our analysis begins to assess the effects of roads and other infrastructure across the landscape of Big Piney-LaBarge oil and gas field. First, we gave the roads and other linear features an initial dimension of 3.5 meters, the average width of single lane roads defined by Trombulak and Frissell (2000). This is a conservative width since some of the roads will be wider. We performed effect zone analyses using widths of one mile, one-half mile, one-quarter mile, 500 feet, 250 feet, and 100 feet. We created these effect zones on the linear and polygonal feature coverages independently and then combined them to create a separate infrastructure effect zone coverage for each width. Finally, we clipped each coverage with the boundary of the study area to remove any portion of the effect zone that fell outside the study area.

Core area analysis. Another commonly used measure for landscape fragmentation is core area, sometimes referred to as interior habitat. Core areas exist in natural landscapes as contiguous blocks of uniform habitat types away from natural breaks or habitat edges. For our analysis, core areas are defined as portions of the landscape that are sufficiently far from human infrastructures or other human modifications to be relatively unaffected by them. Communities of native species and ecological functions persist uninterrupted in these areas.[2]

We looked at habitat patches on the landscape outside of the infrastructure effect zones. For each of the final effect zone coverages described above, we created a corresponding core area coverage. We combined each of the final effect zone coverages with the outer border of the study area to create boundaries for the core areas that lie at the edge of the study area outside the effect zones. This step assumes that core areas adjacent to the study area boundary are indeed core areas.

It is possible for additional infrastructure features to be located immediately outside the study area—features that, if included in the analysis, would increase the acreage that falls within the effect zones and decrease the acreage of core area. Because we considered only those infrastructure features within the study area, we may have overestimated the number and size of core areas.

In the final step, we removed the effect zone polygons, leaving only core area polygons, and calculated the number, size, and overall area of the remaining core areas as well as the percentage of the study area covered by all core areas.

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[2] Fragmentation studies demonstrate that the size and pattern of core areas are important factors in forest landscapes (Baker 1992, McGarigal and Marks 1994, Tinker et al. 1998). Fewer studies have been completed for rangeland landscapes.

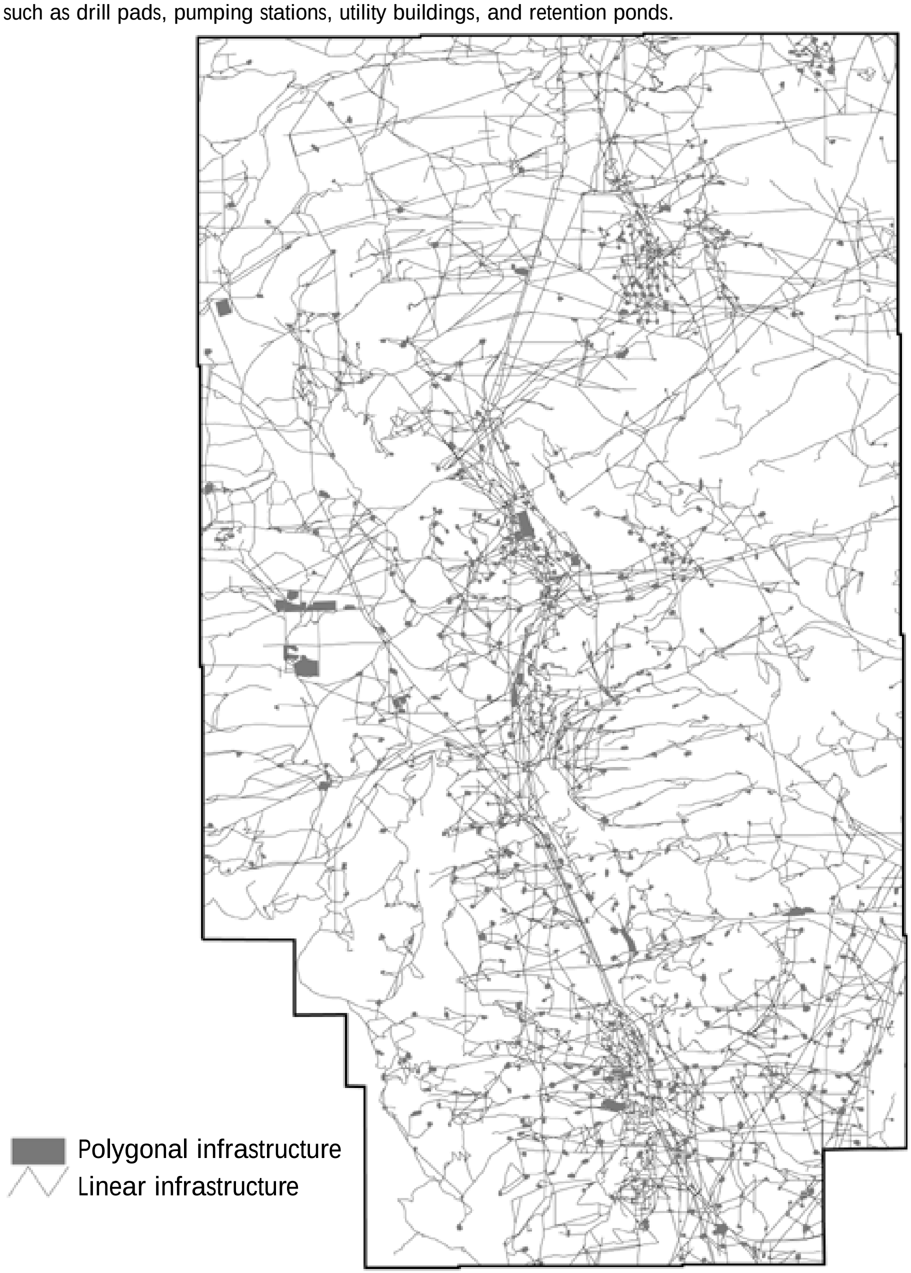
4. Results

All results are based on the digitized linear and polygon infrastructure data described in the methods section and displayed in Figure 2. The data set covers 166 square miles, the bulk of the area for Big Piney-LaBarge oil and gas field, and captures 1,400 miles of linear features and 3.8 square miles of polygon features. The amount of area covered by infrastructure (the physical footprint), and thus the amount of habitat lost, is

FIGURE 2.

The physical footprint of oil and gas development in the Big Piney-LaBarge field

The digitized physical footprint from oil and gas development in the Big Piney-LaBarge field includes both linear infrastructure features such as roads and pipelines and polygonal infrastructure features such as drill pads, pumping stations, utility buildings, and retention ponds.



7 square miles, or 4% of the study area. The ecological footprint is described in the results below.

Density Analysis of Linear Features

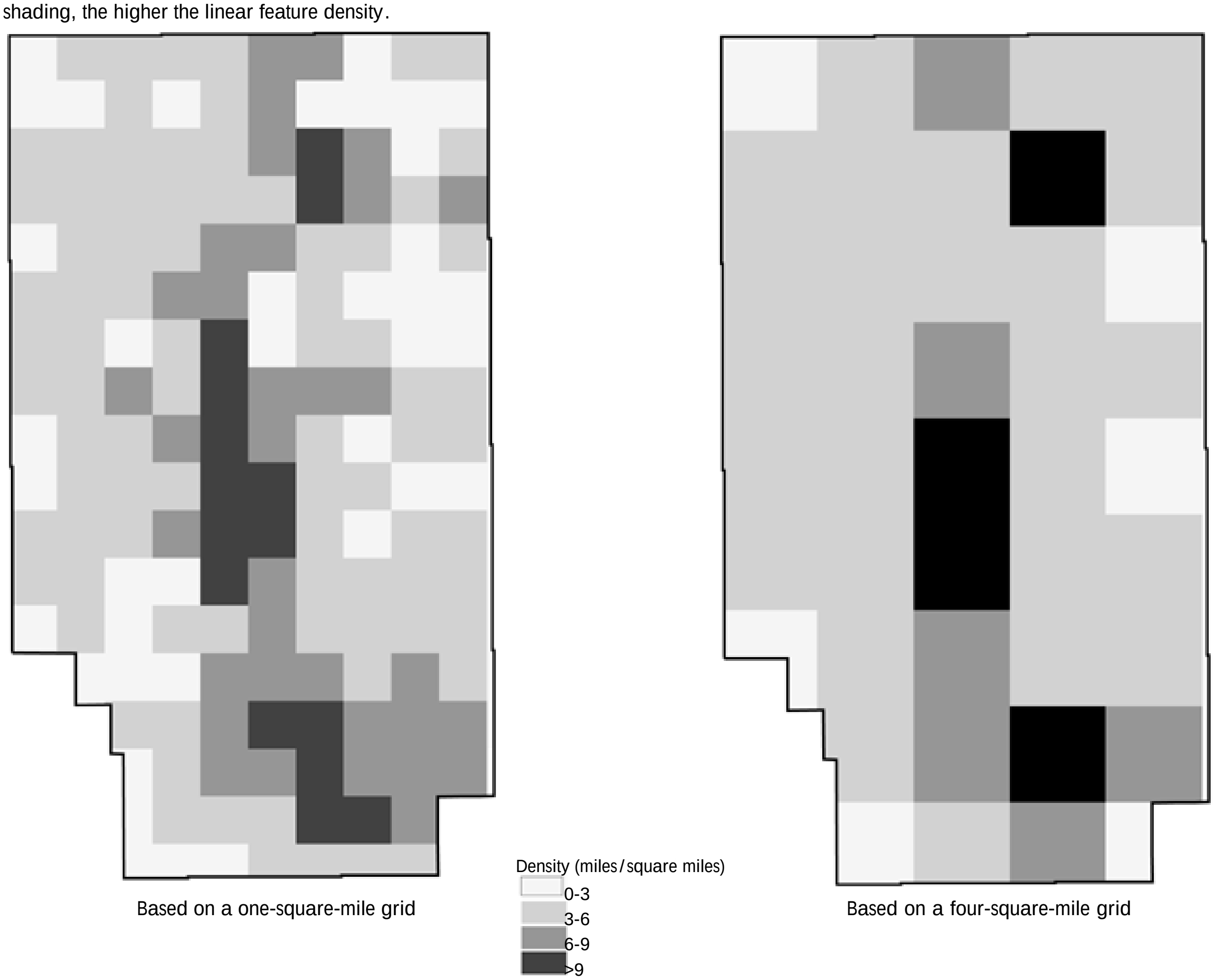
The average density of roads and other linear infrastructure features across Big Piney-LaBarge oil and gas field is 8.43 miles per square mile. However, linear feature density estimates are scale dependent and vary across the study area. To examine local variation in the density of roads and other linear features, we measured densities across both one- and four-square-mile blocks over the landscape (Fig. 3). The results show that densities in the one-square-mile cells range from a high of 17.1 miles per square mile to a low of 0.9 miles per square mile. Densities across the four-square-mile cells range from a high of 11.9 miles per square mile to a low of 2.3 miles per square mile.

Figure 3 illustrates the spatial distribution of linear feature density across

FIGURE 3.

Density of linear features, Big Piney-LaBarge field

The density of linear infrastructure features was calculated using both a one-square-mile grid and a four-square-mile grid. The darker the shading, the higher the linear feature density.



Based on a one-square-mile grid

Based on a four-square-mile grid

the study area. Table 1 shows the percentage of the landscape with different density ranges. The highest percentage of the landscape has a density of between three and six miles per square mile. This is true for both the one-square mile grid, where 49% of the study area falls into this category, and the four-square mile grid, where 64% of the study area falls. It is also important to note that 29% of the landscape in the one-square-mile scenario, and 24% of the landscape in the four-square-mile scenario have linear densities of more than six miles per square mile.

TABLE 1.

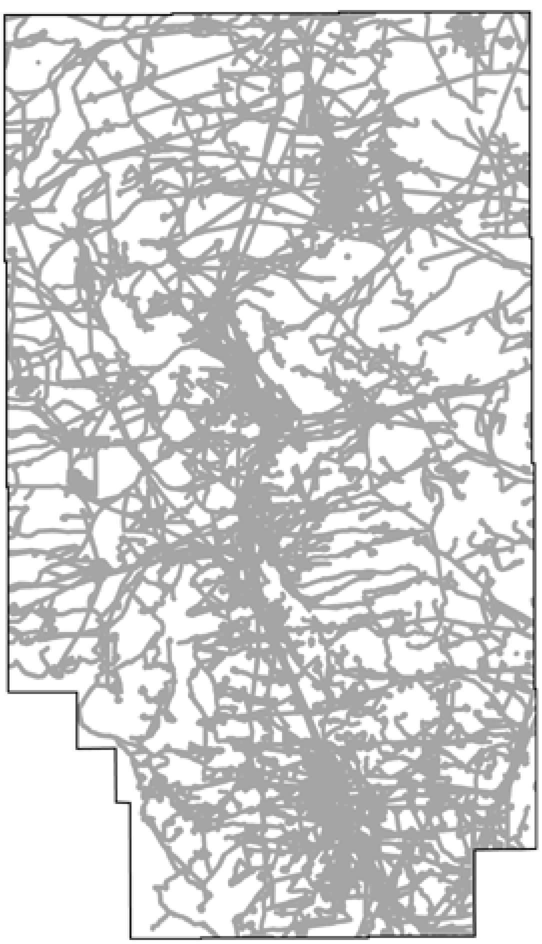
Percentage of the study area that falls within different linear feature density ranges

Linear feature density (miles/square mile)	Based on a one-square-mile grid	Based on a four-square-mile grid
0 - 3	22%	12%
3 - 6	49%	64%
6 - 9	20%	14%
> 9	9%	10%

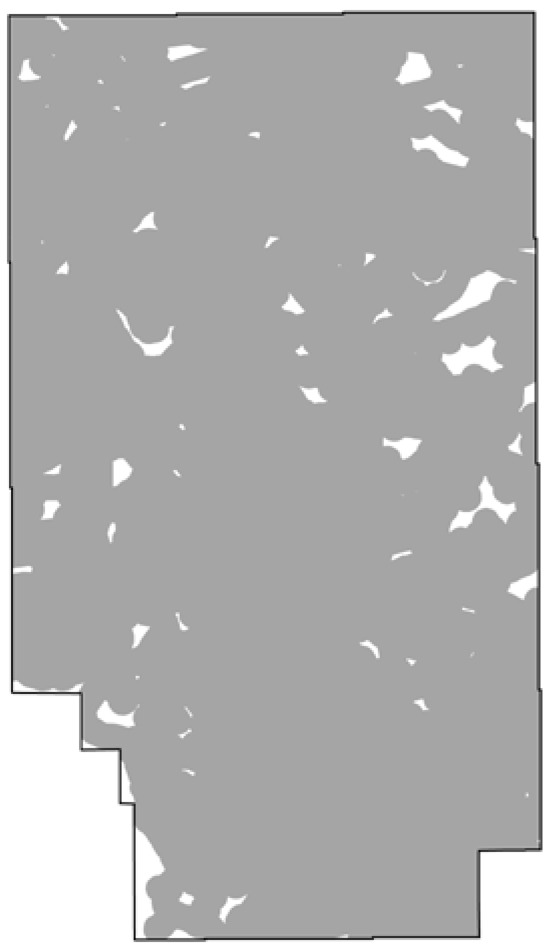
FIGURE 4.

Infrastructure effect zones from oil and gas development

Two examples of infrastructure effect zones based on zone widths of 250 feet and one-quarter mile. Shading indicates the extent of the landscape in the study area that is affected by oil and gas infrastructure.



250-foot effect zone



One-quarter-mile effect zone

Analysis of Infrastructure Effect Zone

Results of the one-mile and one-half-mile effect zone analyses show that the entire 166-square-mile study area is within one-half mile of a road, pipeline corridor, well head, retention pond, building, parking lot, or other component of the infrastructure involved in the oil and gas drilling process. Ninety-seven percent, or 160 square miles, falls within one-quarter mile of infrastructure. When effect zones of 500 feet and 250 feet in width are applied, 73% (122 square miles) and 52% (86 square miles) of the study area fall within the effect zone area. And 28%, or 47 square miles, of the study area is within the 100-foot effect zone. As sample illustrations, Figure 4 shows the scenarios for the 250-foot and one-quarter-mile effect zones.

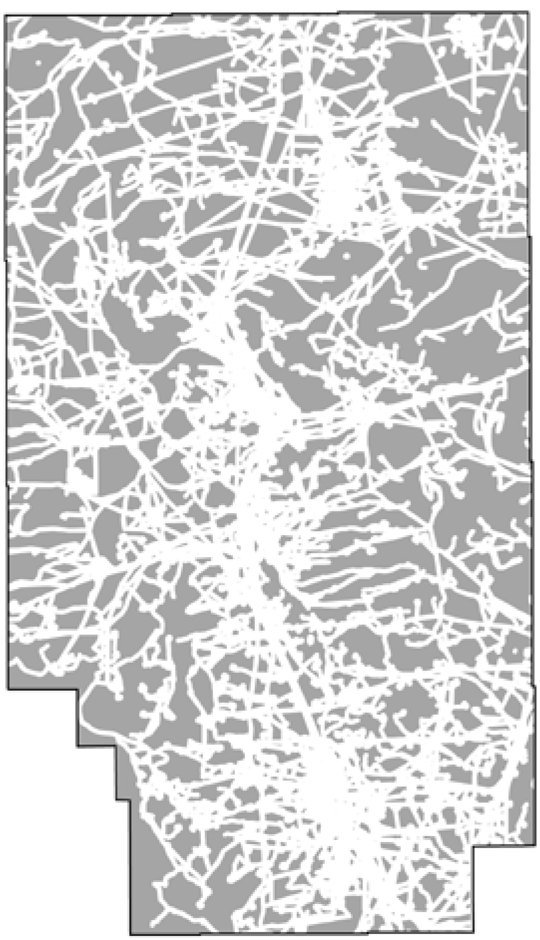
Core Area Analysis

Because our results show that the entire study area is within the infrastructure effect zone when zone widths of one mile and one-half mile are applied, there

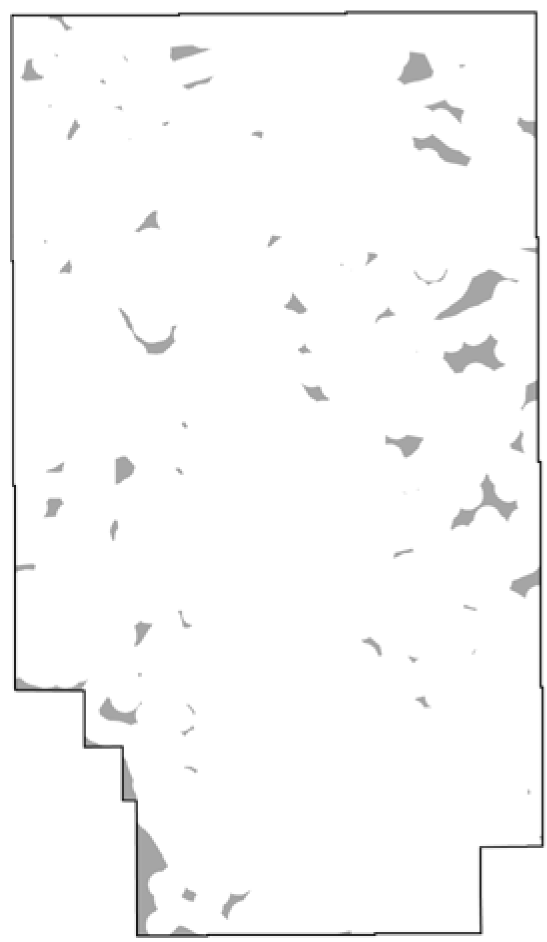
FIGURE 5.

Core area beyond infrastructure effect zone

Two examples of core area maps based on 250-foot and one-quarter-mile infrastructure effect zones. Shading represents the areas beyond relatively narrow and wide infrastructure effect zones.



Core areas beyond 250-foot effect zone



Core areas beyond one-quarter-mile effect zone are no core areas in those two scenarios. Remaining core areas are present when effect zone widths of one-quarter mile, 500 feet, 250 feet, and 100 feet are used (Table 2).

Results show that as the width of the effect zones increases, the total number of core areas decreases as does the maximum core area acreage, the total acreage of core areas, and the percent of the study area remaining in core areas. These results are consistent with an increase in the area of effect.

The results for the minimum core area size are so small in the most heavily developed areas of the study area as to be indistinguishable among the different scenarios. The results for mean core area size actually increase as the width of the effect zone moves from 100 feet to 250 feet and 500 feet because the smaller patches are progressively eliminated, shifting the mean to larger acreages. This effect drops off between 500 feet and one-quarter mile, and the mean core area drops, much as one might expect.

As an example, core areas in the 250-foot and one-quarter-mile effect zones are shown in Figure 5.

TABLE 2.

Summary of results from core area analyses under four different infrastructure effect zone scenarios

	100-foot effect zone	250-foot effect zone	500-foot effect zone	1/4-mile effect zone
Number of core areas	2,871	1,232	499	75
Maximum size (acres)	3,102	2,686	2,042	423
Minimum size (acres)	< 1	< 1	< 1	< 1
Mean size (acres)	27	42	57	46
Total area (acres)	76,214	51,385	28,420	3,457
Percent of study area	72	48	27	3

5. Discussion

Impacts

It is clear from the linear feature density, infrastructure effect zone, and core area analyses that the infrastructure at Big Piney-LaBarge oil and gas field fragments the landscape. We preface the discussion in this section of our report with a list of direct impacts from gas field development. The list is found in the draft environmental impact statement prepared by the Bureau of Land Management (1999) for Pinedale Anticline gas field northeast of our study area.

- Wildlife mortality from wildlife-vehicle collisions on or off project sites.
- Wildlife mortality during road, pipeline, and well-pad construction and other surface-disturbing actions.
- Wildlife mortality caused by consumption of or exposure to toxic compounds.
- Fragmentation of connected habitats.
- Removal of vegetation and other features such as rock outcrops that provide habitat.
- Degradation of aquatic habitats caused by alteration of stream banks and by siltation, and decreased water quality.
- Loss of forage for herbivores.
- Diminished animal use of habitats because of the effects of noise, dust emissions, and the presence of humans.
- Interruption or interference with wildlife life-history functions, including courtship, nesting and parturition, migration, and winter survival.

Many of these impacts persist over time, and additional impacts can be expected after full development of an oil or gas field. Comer (1982) lists several.

- Increased recreation, particularly by off-road vehicles.
- Increased conversion of habitat, especially for urban or suburban sprawl.
- Habitat degradation through encroachment by people.
- Increased noise, air, and water pollution.
- Increased poaching of game species.
- More numerous wildlife deaths on roads.
- Increased harassment of wildlife by uncontrolled pets, especially dogs.
- More invasions of non-native species.

Most of the impacts on these lists apply to the physical footprint—1,400 miles of linear features and 3.8 square miles of polygon features—left on Big Piney-LaBarge gas field. Many also extend beyond the physical footprint and require landscape analyses such as those we conducted to describe the extent of the area affected by these impacts.

Landscape Metrics

As described earlier, our density figures include other linear features in addition to roads (primarily pipelines). The majority of the features are roads, and all produce a significant break in natural vegetative cover. It is therefore useful to compare our linear feature density estimates to road density estimates elsewhere on public lands.

Road densities on national forests in Wyoming, South Dakota, and Colorado, for example, range from 0.42 miles per square mile to 2.37 miles per square mile (Baker and Knight 2000), nearly three times less than the density we document at Big Piney-LaBarge. The Interior Columbia Basin Ecosystem Management Project (U.S. Forest Service 1996) classified road densities as extremely high when they reach 4.7 miles per square mile. Based on this criterion, the overall density of 8.34 miles per square mile at

Big Piney-LaBarge suggests that tight gas drilling results in a highly fragmented landscape.

In more open landscapes such as the desert sagebrush environment of our study area, wildlife species are particularly vulnerable to the effects of disturbances and will be impacted by even lower road densities than those listed for forested landscapes in the preceding paragraph (see wildlife section below).

It is notable that local road densities exceed three miles of road per square mile over most of the study area. At all oil and gas production areas, a comparison is needed between the average and localized road density figures and the road density figures in the ecological literature to determine the impacts on specific terrestrial and aquatic species.

While the physical footprint, or the actual oil and gas infrastructure, comprises only 4% (seven square miles) of the study area, the infrastructure effect zone analyses show that the ecological footprint is much larger. The ecological footprint varies depending upon which disturbance is measured. A disturbance that reaches a quarter of a mile beyond the infrastructure creates a footprint of 160 square miles, affecting 97% of the study area. Even a more localized disturbance that only reaches 100 feet beyond the infrastructure affects 28% of the study area (47 square miles).

When choosing the appropriate effect zone widths for analysis, it is important to consider the particular disturbances that impact the area in question and which specific physical, biological, or human effects the disturbances have on the landscape. For example, the size of the effect zones should be constructed with widths that reflect documented effects on specific species in the study area.

Likewise, core area results should be compared to the size and shape of areas needed by local species for dispersal, breeding, and other life-history functions. As more scientific information becomes available regarding the specific habitat requirements of pronghorn antelope, mule deer, and sage-grouse, it can be used to formulate landscape analyses to assess the impacts of future development in the area.

In addition to considering the size and shape of remaining core areas, the connectivity of those core areas is critical to wildlife. If certain species must migrate between core areas and are unable to do so, the fact that there may be a large number of core areas with significant acreage will mean little to their survival.

While this study looks at core areas only as a function of infrastructure, assessments of core areas should also take into account the natural variation in vegetation cover patterns. And naturally occurring core areas should be compared to core areas that are caused when natural patterns are fragmented by oil and gas development infrastructure.

Future work should discriminate between types of linear and polygon features and their different effects on the landscape, if the data are available. For example, a frequently used road should be treated differently than a remote pipeline, as should an automated drill pad and a frequently used utility site. Such distinctions would allow researchers to calculate linear feature densities independently for features with differing impacts and to measure the edge effect zone at different widths for features with differing degrees of disturbance. This in turn would change the size of the core areas and potentially produce more accurate and useful landscape metrics.

Wildlife

The Upper Green River Basin is home to at least 25 species that the U.S. Fish and Wildlife Services lists as threatened or endangered, including the black footed ferret, whooping crane, bald eagle,

The overall linear density of 8.34 miles per square mile at Big Piney-LaBarge suggests that tight gas drilling results in a highly fragmented landscape.

mountain plover, northern goshawk, peregrine falcon, and spotted frog (Bureau of Land Management 2001). As noted earlier, the study area is also wintering ground for elk, pronghorn antelope, and mule deer.

The large number of oil and gas fields in this basin block natural migration routes and encroach on crucial wildlife wintering grounds. Numerous studies document that elk avoid roads and, according to Lyon (1983), do not use habitat adjacent to roads to its full potential. Lyon found that when road densities are as low as one mile per square mile, elk habitat effectiveness is reduced by 25%. When road densities are two miles per square mile, elk are displaced from up to 50% of their habitat. When road densities exceed five to six miles per square mile, elk are unable to use more than 75% of the habitat and may not use any of the potentially available habitat. Roughly a quarter of our study area falls within the latter category.

As noted above, road avoidance by wildlife is particularly evident in open landscapes with little surrounding vegetation (Perry and Overly 1976, Morgantini and Hudson 1979, Rost and Bailey 1979). In areas with little cover, habitat is completely lost at a road density of only 0.8 miles of road per square mile (Lyon 1979).

A study on elk habitat effectiveness, in north-central Wyoming found that few elk used areas with road densities higher than 0.5 miles per square mile (Sawyer et al. 1997). Again, our results indicate that most of our study area has linear feature densities much higher than 0.5 or 0.8 miles per square mile.

Another study in western Wyoming indicates that elk are avoiding a relatively high-density oil and gas field in open habitat (Bock and Lindzey 1999). The lack of physical barriers to screen drilling activities has displaced elk up to three miles.

Perry and Overly (1976) concluded that more than 640 acres of elk habitat can be affected by one mile of road, while a radiotelemetry study by Edge and Marcum (1991) measured a 5% probability of elk using lands within one kilometer of a road during calving season.

Wyoming has by far the greatest concentration of pronghorn antelope in any state or provincial authority in North America, and the Green River Basin holds the highest concentration of this animal in Wyoming (Bureau of Land Management 2000). In addition, western Wyoming boasts the longest pronghorn migration in North America—up to 190 miles, depending on the route chosen, from Grand Teton National Park to winter range near the Jonah Field in the Upper Green River Basin. Archaeological digs indicate that this migration has continued uninterrupted for more than 6,000 years (Sawyer and Lindzey 2000).

The antelope are known to have crucial and non-crucial winter ranges, as well as spring, summer, and fall ranges, in Big Piney-LaBarge gas field (Bureau of Land Management 1999). BLM documents indicate that antelope in the nearby Whitney Canyon-Carter Lease fields felt the impacts of oil and gas projects with “nearly one mile of road per every square mile of occupied habitat” (Bureau of Land Management 1999). Our study area has average linear feature densities more than eight times greater than one mile per square mile.

The bulk of the study area is designated as mule deer winter habitat (Bureau of Land Management 1990). Mule deer have also been shown to avoid oil and gas development in their habitat. A study conducted in North Dakota found that mule deer avoided areas within 300 feet of well sites for feeding and bedding, resulting in a 28% reduction in secure bedding areas. Their avoidance of roads and facilities continued for more than seven years, indicating a long-term and chronic loss of habitat (Jensen 1991).

Wildlife species other than big game animals also face the impacts of infrastructure. Southwestern Wyoming is considered the location of the largest and most robust North American population of the greater sage-grouse. Wyoming has more than 150 identified leks (breeding grounds)—key to greater sage-grouse survival—about two-thirds of which are located in Upper Green River Basin (Bureau of Land Management 1999). The population and distribution of greater sage-grouse across the West has decreased in the past 50 years as a result of habitat loss, and the decline has been dramatic in the past 20 years (Christiansen 2000). For this reason, the greater sage-grouse is being considered for listing under the Endangered Species Act.

Greater sage-grouse are affected by oil and gas development for miles beyond the infrastructure itself. A recent study (Lyon 2000) in Wyoming compared the behavior of females captured on leks within two miles of natural gas development to those captured on undisturbed leks (farther than two miles from any gas development). The study found that the hens captured on disturbed leks had lower nest-initiation rates and moved longer distances to nest sites than hens captured on undisturbed leks.[3] Given our results, then, there is no place in Big Piney-LaBarge gas field where the greater sage-grouse would be unaffected by natural gas development.

PHOTO COURTESY GARY KRAMER, U.S. FISH AND WILDLIFE SERVICE

Greater sage-grouse, a species that is being considered as a candidate for listing under the Endangered Species Act. The results of our study show that there is no place in Big Piney-LaBarge gas field where this species will not be affected by the gas extraction project.

Other bird species have been shown to decline in oil and gas fields of the Upper Green River Basin. Ingelfinger (2001) measured the distribution of birds along dirt roads in the Jonah Field II and the Pinedale Anticline Project Area. Results showed a 50% decrease in Brewer's and sage sparrows and the guild of sagebrush obligates within 100 meters of a road. Ingelfinger pointed to traffic and changes in habitat use as causes. A distance of 100 meters falls in between our impact zones of 250 feet and 500 feet, and thus our results suggest that the presence of Brewer's and sage sparrow and the guild of sagebrush obligates may also be reduced by half across 52% to 73% of Big Piney-LaBarge gas field.

[3] According to a recent report in *Wyoming Wildlife News* (Christiansen 2000), "Only 67 percent of the hens captured on strutting grounds near disturbance (well pads or roads) attempted to nest. This compares to 89 percent of the hens captured on a relatively undeveloped location. In addition, only 47 percent of the disturbance site birds remained within two miles of the disturbance during nesting while 89 percent of the undisturbed birds remained within two miles of where they were captured. Both groups had 50 percent of their nests hatch. This means that if 100 hens were associated with the disturbed and undisturbed sites and both groups had six chicks hatch from each successful nest, then the area within two miles of an undisturbed strutting ground would have hatched 238 chicks while only 94 chicks would have hatched within two miles of a disturbance."

Additional Concerns[4]

Our analysis is limited to a single spatial scale—that of the Big Piney-La Barge field. But oil and gas development may affect ecological phenomena at other scales as well. For example, we mentioned but did not analyze the potential effects of oil and gas development on animal migration. A comprehensive spatial analysis should examine impacts at multiple scales to understand this phenomenon.

A complete spatial analysis should also examine the effects below and above the land surface. Hydrocarbon extraction and fluid injection can have substantial impacts, including drawdown and contamination, on both shallow and deep aquifers. It is important to gather baseline data and predict the subsequent effects on natural systems and local agricultural and residential water users.

The oil and gas production process also emits pollutants into the atmosphere, including greenhouse gases. The Big Piney-LaBarge processing plant vents six million tons of carbon dioxide into the atmosphere every year (Allis et al. 2001). To compare, the theoretical carbon dioxide emissions from a 1000-megawatt coal-fired plant are assumed to be nine million tons per year (U.S. Department of Energy 1999).

[4] The condition of local wildlands affects a region's recreation opportunities and its ability to attract and maintain a quality work force. Aplet et al. (2000) documented six features that contribute to the wildness of a landscape: opportunities for solitude, remoteness from mechanical devices, natural ecological processes at work, natural vegetative and wildlife species composition, no alterations by human structures, and low levels of pollution. Our analysis of infrastructure documents a decrease in the level of solitude, remoteness, and natural species composition and an increase in human structures in the study area. These factors should be considered in assessments of the impacts from oil and gas projects—for local communities and for people who visit from more distant locations.

6. Conclusions and Recommendations

Despite the documented impacts that habitat fragmentation has on wildlife, proposed oil and gas projects are moving forward without adequate evaluation of those impacts. Land managers sometimes excuse their lack of evaluations by stating that data are insufficient to conduct impact assessments.

For example, the draft environmental impact statement that evaluates the effects of coal bed methane development in the Powder River Basin of Wyoming asserts in its wildlife section that it is difficult to assess the effects of roads and habitat fragmentation "because these determinant factors are largely unknown at this time" (Bureau of Land Management 2002). At the same time, the document concludes that there is enough habitat elsewhere to mitigate any habitat loss caused by fragmentation.

Comments on that document penned by a wildlife ecologist state:

> The relevance of the fragmentation process affecting wildlife populations rests on the understanding that information on habitat amount alone may be insufficient to predict the status of a species. When habitat is potentially limiting, then information on the spatial pattern of the habitat may be equally or more relevant than information on habitat amount. The importance of incorporating spatial data into effects analysis cannot be overemphasized. Knowledge of where on the landscape habitat loss will occur and in what spatial pattern is essential before one can conclude no significant adverse effects (Noon 2002).

This study has demonstrated three landscape metrics—linear feature density, infrastructure effect zone, and core area—for use in assessments of fragmentation across a landscape. These metrics, along with the ecological literature, illustrate that the ecological footprint from oil and gas development is much larger than the physical infrastructure footprint. Such spatial analysis can and should be incorporated into the evaluation and monitoring of the ecological impacts of existing and proposed oil and gas projects. When land management agencies consider plans to develop an area for its oil and gas resources, the required environmental impact statement should include similar analysis at the landscape level. The significant increase in availability and access of GIS data and software technology in recent years should make this possible.

We performed our analysis on data derived from an existing oil and gas field. The same kind of analysis should be performed prior to development of a new oil and gas field or when planning additional development in an existing field. The following recommendations for landscape assessments act as a guide for completing environmental evaluations to assess the true ecological footprint of potential oil and gas extraction prior to field development.

Generate infrastructure scenarios. Infrastructure data for all linear and polygonal features should be generated to construct scenarios for the proposed oil or gas field. Multiple road scenarios should be provided for the range of potential infrastructure, depending upon the type of resource extracted and the required support facilities. The scenarios should include generous and conservative estimates of infrastructure construction, based on probabilities for hydrocarbon resources in the field. Particular care should be taken if unconventional or continuous type deposits are involved because "[l]and-use planners are not in a good position to determine the societal impacts of the drilling (density) that would be necessary if these continuous reservoirs of (tight) gas were exploited" (U.S. Geological Survey 1996b).

Assemble habitat use information from published literature where available for threatened and endangered species and other key plant and animal species in the proposed development area. The goal is to provide data needed to devise the parameters of metrics and for interpretation. The information should include, but not be limited to, impacts of road density on local species, distance of road effects to determine the width of effect zones for infrastructure features, and species dispersal distances to evaluate the size of core areas.

Generate landscape metrics. Calculate landscape fragmentation metrics on all infrastructure. Include at a minimum infrastructure density, infrastructure effect zones, and core areas. Metric parameters and the evaluation of results should be relevant to ecological conditions, species that are present, and human uses of the landscape in question.

Integrate results into management plans. Evaluate landscape fragmentation metrics of effects to determine the impacts on specific local species. Include these ecological footprint impacts along with other ecological impact data in federal planning documents throughout the planning process for potential development of oil and gas fields.

This landscape assessment comparing the impacts of extracting oil and gas resources with the maintenance of wildlife, habitat, and recreational resources fits well with existing federal environmental regulations. Such analyses should become a standard part of the environmental assessments, environmental impact statements, resource management plans, and coordinated activity plans conducted by the U.S. Forest Service and Bureau of Land Management. The Federal Land Policy and Management Act of 1976, which guides BLM management of public lands, specifically requires the "harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land and the quality of the environment with consideration being given to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or the greatest unit output."

Comprehensive assessments of the ecological footprint should incorporate spatial analyses that extend beyond the scope of this study to include an assessment of landscape context and impacts on the subsurface and atmosphere. It is essential to evaluate the ecological role of the proposed field of development in the broader landscape. Consider both the content and function of the area. For example, does this landscape provide a food source, breeding ground, or seasonal range for threatened or endangered species that is not available in the surrounding landscape?

It is important to include analyses of hydrologic impacts such as drawdown or contamination for shallow and deep aquifers. These impacts should be evaluated for their short- and long-term ramifications related to ecosystem and societal needs for the water resources. Likewise the atmospheric emissions from extraction and processing need to be measured for their content, volume, and distribution.

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